to which I might refer in connection with this very interesting address, that you need not go quite so far as the Balkan States to find churches which are built for the purpose of defence. I have seen one in Wales, not very far from Llandrindod, that was distinctly built for defence in very ancient times when defence depended on the bow and arrow. I ask you to unite in a very cordial vote of thanks to Mr. Berry for one of the most interesting addresses we have heard here, and at the same time to thank those who have taken part in the discussion which has followed.

A TRANSFORMATION OF THE MAGNETIC DIP CHART

E. A. Reeves, F.R.A.S., Map Curator R.G.S.

Chart following p. 208.

IF we turn to any magnetic charts of the world showing curves of equal inclination or dip we must be struck at once with the great irregularity of these curves, and their apparent lack of symmetry. This is noticeable both in the northern and southern hemispheres, but especially in the latter, where they diverge in a most remarkable manner.

These equal inclination curves represent positions on the Earth's surface where the dipping needle, when placed in the magnetic meridian, comes to rest at the same angle with the horizon. The angles, however, are measured, not from any common datum that is constant for wherever the observation is taken, but from the horizon of the place; hence their great irregularity. The horizons not being parallel, equal inclinations to the horizon do not imply equal inclination to any common axis of reference; and for purposes of discussion curves of equal dip are not necessarily convenient.

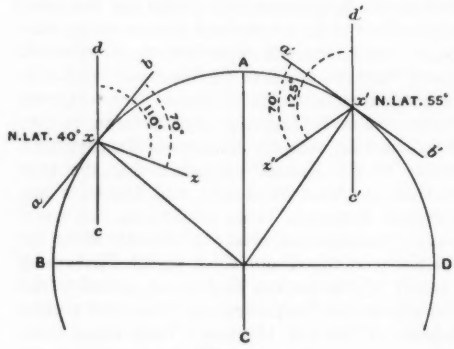


Fig. 1.

Suppose ABCD (Fig. 1) to be the true meridian, AC the geographical axis of the Earth, and BD the equator. Now at x in N. altitude 40°, suppose the inclination measured to be 70° below the horizontal; the position the needle will take will then be shown by the line xz, and the horizontal line by the line ab. Next, let another observation be taken on the same meridian, but on the opposite side of the pole, say at x', in N. latitude 55°, and again let the inclination measured be 70° below the horizontal, $a'b'$, the needle coming to rest in the line $x'z'$. In these two

places, then, the inclination as measured from the horizontal is the same, and the curve of 70° equal inclination is made to pass through them both; but the horizons from which the inclinations are measured are not parallel with one another.

It appears, then, that although inclination or dip may be most conveniently measured from the horizontal, it is important to remember that it is so measured, and that if referred to any common axis of reference the angles will no longer be equal or similar angles. For instance, let the line AC, the geographical axis, be taken as the basis of measurement, and cd and $c'd'$ be drawn through the points x and x', parallel with this line. Then, although in both cases the angle of inclination from the horizon line is 70°, it will be seen at once that when reduced to these parallels, cd and $c'd'$, at x the inclination will be 110° and at x' 125°. In fact, in this case x would have to be moved much nearer the geographical pole, A, before its axial inclination equals that of the station x'.

In order to ascertain what would be the result of reducing the inclination curves to a fixed axis of reference, the annexed charts of the Northern and Southern Hemispheres have been prepared from a large number of computations made in my spare time during the past few months. The first point to be considered was the most suitable line to be taken as the common axis. I had thought of taking a straight line joining the dip poles; but for several reasons this was soon found to be quite unsuitable. The so-called dip poles are not 180° apart in longitude, neither are they in similar latitudes in the north and south polar regions; consequently a straight line joining them would not pass through the centre of the Earth. Then again, the dip poles seem to bear little relation to the areas of maximum total intensity, which probably influence the direction taken up by the needle. There seemed no advantage in taking an axis such as Gauss' theoretical magnetic axis. I therefore decided that the most reasonable line to take as the axis of reference of the curves was the geographical axis of the Earth, or its axis of rotation, and the result has led to some interesting results which I think fully justify the selection I have made.

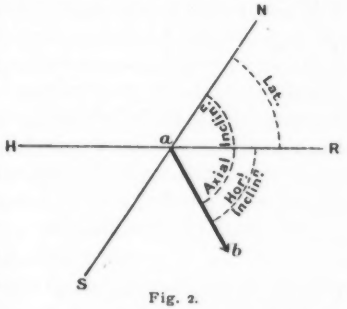


Fig. 2.

Referring now to the charts, the red curves run through the positions where the dipping needle comes to rest at the same angle with the geographical axis of the Earth; where the north-seeking end of the needle dips below the equatorial horizon, the angle is measured from the north end of the axis; and where the south-seeking end dips it is measured from the south end of the axis. To make this clear, suppose NS (Fig. 2) to be a line parallel with

the geographical axis, and *ab* a dipping needle which is freely suspended at *a*; the angle that the needle makes with the north end N of the axis is the angle N*ab*. At points on the Earth where there is no 'variation' this angle can be obtained at once by adding the latitude to the horizontal inclination or dip; but otherwise the declination of the needle must be allowed for, and the angle can only be obtained by spherical trigonometry, as follows:

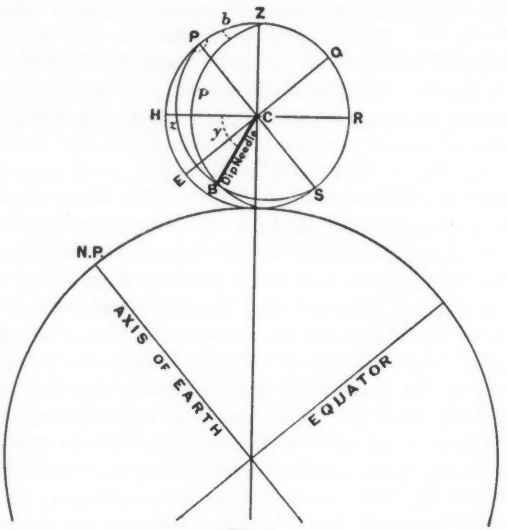


Fig. 3.

In the spherical triangle PZB (Fig. 3) PS is a line parallel with the axis of the Earth, Z the zenith, and HR the horizon line. BC represents a dipping needle at the angle y below the horizon. The side p is then $90° + y$, the side b equal to the co-latitude of the place, and the angle at Z that the side b makes with the side p (shown by Z in the computations) the angle of declination of the needle, or the variation of the compass. Then in the spherical triangle PZB the two sides b and p, with the included angle Z, are known, and it is required to find the third side z, which is the axial angle of inclination, or the angle that a freely suspended dipping needle makes with the axis of the Earth.

The angle z is then given by

$$\sin z = \sin p, \sin Z, \operatorname{cosec} P$$

P having been previously found from

$$\tan \frac{P + B}{2} = \frac{\cos \frac{1}{2}(b - p)}{\cos \frac{1}{2}(b + p)} \cot \frac{Z}{2}$$

$$\text{and } \tan \frac{P - B}{2} = \frac{\sin \frac{1}{2}(b - p)}{\sin \frac{1}{2}(b + p)} \cot \frac{Z}{2}$$

In this way points for plotting the curves were obtained at every 20° of latitude and 30° of longitude up to latitude 60° north and south of the equator, taking the inclination and declination angles from the Admiralty Charts for 1907, and supplementing the points by making use of the 'No variation' line wherever it occurred along the selected parallels, and on the intermediate 10° of latitude.

Above latitudes 60° N. and S. the same charts were used for the few degrees higher in latitude that they include; but beyond this the observations of Polar expeditions, and Dr. J. Neumayer's charts in Berghaus' *Physikalischer Atlas* have been used. An attempt has been made in places to bring these latter data to the epoch of the Admiralty Charts, but so little is known of the secular change in high latitudes that the figures here can only be approximate. Still, they are not likely to be much in error, and doubtless quite accurate enough for giving a good general idea of the direction taken by the curves. Later on many more angles were computed in the equatorial regions in order to trace the 10° curves and their points of convergency.

In the computations no great accuracy was attempted, nor indeed was possible, since the data had to be scaled off the charts; but the results of the computations are more than sufficiently exact for the plotting of the curves. Five-figure logarithms were used, but no attempt was made, except in a few instances, to work to nearer than 1′. Possibly the greatest error in the computed angles would not exceed 4′, apart from errors due to the fact that the data are only scaled off the charts. After all these charts are only preliminary productions, and it would be well, if anything further is done in the matter, to compute more points, taking them, and all the others, from the actual observations instead of scaling from the charts.

No special importance has been given to the magnetic poles, or areas of 90° dip or inclination below the horizon; and they have been treated just as all the other points. The fact that the dip is 90° below the horizon in these areas is in itself probably of no great significance. Other areas have been found where the dip is 90°, one of which was only recently discovered by Dr. Bauer s party at Treadwell Point, Alaska (see Dr. Hale's article in the 'Annual Report of the Board of Regents of the Smithsonian Institution,' 1913, p. 147), so that this fact alone may mean very little. It may, however, be interesting to see what takes place as regards the new curves at these dip poles. The north magnetic pole is approximately in 70° 5′ N. lat. and 97° W. long., while the south magnetic pole is roughly situated in 72° 30′ S. lat. and 153° 45′ E. long. Taking the north magnetic pole as an example: Since there is no 'variation,' all that has to be done to obtain the axial inclination is to add the latitude 70° 5′ to the 90° inclination (horizontal) and the result is 160° 5′, which is the angle required. This case is given in Fig. 4; and it appears probable that somewhere only a few degrees from the geographical north pole (perhaps near the mean centres of the axial inclination curves) the angle would be

about 180°. The same holds good for the south polar regions; only there, since the distribution of total intensity is very unequal, being much greater on the South Victoria Land and Australia side than the South America side, the point of 180° axial inclination is likely to be further from the geographical pole.

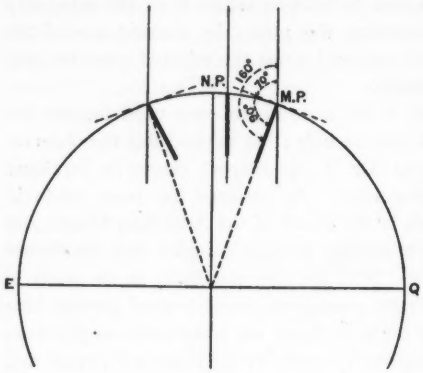


Fig. 4.

The red spots on the charts show approximately the mean centres of the new curves, and it will be noticed that both in the north and south polar regions these are about 6° to 8° from the geographical poles.

Owing to irregularities, especially in the declination, the minimum axial inclination angle computed in the equatorial regions frequently exceeds 10°. The lowest angle found is about 1°·5, and this is in lat. 10° S. and long. 58° W. Somewhere quite near here there may be a point where it reaches 0°. The only other area where it seems possible that such a low angle will be found is between Ceylon and Sumatra, where the angles are again very small.

It will be clear that since there are parts where the minimum angle exceeds 10°, the axial inclination curves of 10° are not continuous round the Earth as is the case with the others, but are closed at the ends where they converge and meet at certain points as shown on the charts. Curves showing smaller angles, such as 5°, would, for the same reason, form ovals within the 10° curves.

A very important feature which I think the charts bring out is the connection between the centres of maximum total intensity and the direction taken up by the magnetic needle as indicated by these new inclination curves. In the northern hemisphere there are two areas of maximum intensity, one in North Siberia and the other in Arctic America; the latter, where the land extends to a higher latitude, being somewhat stronger than the former. Now, it will be noticed that the new axial inclination curves are roughly elliptical near the geographical north pole, and are apparently drawn out in the direction of these two centres of maximum intensity, being drawn more towards the American centre than towards that in Siberia. Further, it will be seen that at right angles to these centres the intensity is greater on the Bering Strait side than on the opposite European side; and here again the curves are drawn out towards the area of greater intensity, although not anything like to the same extent as in the direction of the Siberian and American maximum centres.

In the southern hemisphere there appears to be only one centre of great intensity, or if there are two the second is in the neighbourhood of the first and on the same side of the geographical pole, so that the two may be considered to act as one for our purpose. This combined centre is between Tasmania and South Victoria Land; but here again it is noticeable that the curves of axial inclination are drawn in the direction of this centre. As there is no corresponding centre on the opposite side of the south geographical pole, the deflection of the curves of inclination is all in one direction, as indeed it should be; on the side opposite the centres of maximum intensity the curves appear to be drawn in towards the geographical poles, as indeed might be expected.

The centres of maximum total intensity in the northern hemisphere are both in the northern parts of the great land masses, and in the southern hemisphere the centre, single or combined, is in the neighbourhood of the greatest land masses in high southern latitudes, that is, it is in the South Victoria Land, Tasmania, and Australia section; and this seems to point to the conclusion that the distribution of land and water on the Earth's surface has a great deal to do with the distribution of the magnetic intensity, either by the indirect and consequent effect of temperature or in some other manner not yet fully explained. However, it seems likely that if the Earth's surface were altogether composed of one material, such as land of equal formation and magnetic permeability, the magnetic intensity would be arranged in more or less regular zones following the parallels of latitude and increasing from the equator to the poles.

It appears to be the distribution of magnetic intensity over the Earth's surface that affects the direction taken by the needle, and not the positions of the 90° dip poles. Further, if we consider the question of declination, the compass takes up that position in the lines of force with regard to its horizontal orientation in which it is balanced by the surrounding magnetic forces, and rarely points to the magnetic poles of 90° dip. In fact, as a rule it points to no pole at all.

It is not my intention to attempt any discussion on the theory of the complicated subject of terrestrial magnetism, and these notes have been written only as explanatory of the charts and the manner in which they have been constructed; but from what has been said I think it must be concluded that the selection of the geographical axis of the Earth as the axis of reference for the new inclination angles is the best to be found, and, as has been pointed out, it is certainly in agreement with the distribution of magnetic intensity and the maximum centres. The regularity of these new axial curves as compared with curves of dip measured from the horizon is another matter to which I would call special attention, and it seems to furnish additional proof that the line which I have chosen is not an unreasonable one to take for the reduction.

In order to show that the difference in the regularity in the curves is not due to distortion caused by the projection on which the charts have

been constructed, I have also drawn them, or as many of them as I could conveniently show, on a globe, and proved clearly that this is not the case.

The charts of the northern and southern hemispheres first drawn were both for the year 1907, but as it seemed desirable to arrive at some idea of what change is taking place in the curves, I have since completing these drawn others for a much earlier date, the year 1700. The data for these are by no means so trustworthy as for the 1907 charts, but I have taken the best I know, the tables and charts of inclination, declination and intensity given for that year in Dr. H. Fritsche's 'Atlas des Erdmagnetismus.' As the work of computing the points for the reduction of the curves is very considerable, except in the polar regions, I have not taken so many as in the case of the 1907 charts, but quite sufficient I believe to

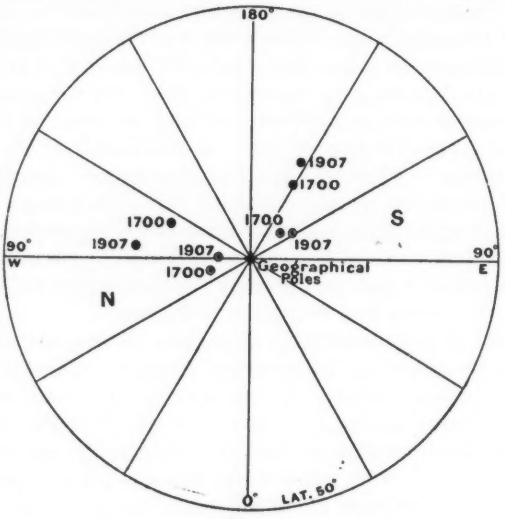


Fig. 5.

give the general form and direction of the curves. A comparison of the charts for the two dates should be interesting, and in a general way perhaps help to show what changes have taken place in the magnetic elements during the interval of 219 years.

Perhaps the most important point is the relative positions of the mean centres of the new axial curves with reference to the magnetic and geographical poles. These positions are all shown on one diagram with the geographical pole in the centre. On this diagram (Fig. 5) the positions of the magnetic dip poles and those of the mean centres of the axial curves for 1700 and 1907 are all indicated, the former by ● and the latter by ⊙. On the same diagram the south magnetic pole and the mean centres of the southern axial curves for 1700 and 1907 are also

shown in the positions where they would be seen if it were possible to view them through the Earth. This method has the advantage of exhibiting not only the positions of these points with reference to each other, but of bringing out more clearly than I could find any other way of doing the relative longitudes of the northern and southern magnetic poles and axial centres, and the fact that they are by no means 180° apart. The mean of the positions on the 1907 charts shows that the distance between the geographical poles and the centres of the curves is very nearly one-third the distance between the magnetic and geographical poles, while the mean of all four charts, although somewhat more than one-third, does not differ widely from this.

This is an important fact, and one to which Prof. A. Schuster, who saw the 1907 charts with the first part of these notes, calls attention in a letter. He says that he has assured himself "that on the supposition of a uniformly magnetized sphere the lines of equal angle between magnetic force and the direction of the Earth's axis should be closed curves approximating circles round a point between the magnetic and geographical poles, and one-third of the distance from the geographical pole. This, in fact, is the main feature of Reeves' curves, as the required fraction of distance ($\frac{1}{3}$) is very nearly satisfied."

The mean centres of the axial inclination curves have been obtained by finding graphically on the original large-scale charts the centre of the separate curves for each chart, and then obtaining their mean position. These must be considered as approximate only, but are probably not more than a degree or so in error in any case. According to these charts the mean distance of these centres from the geographical poles for the 1907 are :

Northern hemisphere	5°·5
Southern „	8°·5
	7°·0 mean.

And for the 1700 :

Northern hemisphere	7°·0
Southern „	6°·5
	6°·7 mean.

Thus it will be seen that the mean distance of these centres from the geographical poles is nearly the same for both although the interval in time elapsed is over two hundred years.

An interesting relation exists between the axial inclination curves, the geographical latitudes, and the distance of the mean centres from the geographical poles, which is that *half the mean of the axial inclination angles round any parallel of latitude minus the distance of the mean of the N. and S. mean centres of the curves from the geographical poles equals approximately the latitude.* As in many cases the data can only be rough,

and as in parts, especially in the polar regions, comparatively few points are available for the computation of the curves, it was not likely that very accurate values would be obtained, but the results are sufficiently near to show that this relationship exists. The rule may be thus briefly expressed:

$$\lambda = \frac{a}{2} - b$$

where λ = geographical latitude.

a = mean of axial inclination angles round any parallel of latitude.

b = mean distance of N. and S. centres of axial inclination curves from the geographical poles.

The distances of the mean centres of the axial curves, b, from the geographical poles were, in the first place, merely scaled off the charts, and a table worked out with these values; but by transposing the formula it is possible to obtain the distances of b from the geographical poles from the known latitudes and the computed axial inclination, since the relationship clearly exists.

The formula for this would then be

$$b = \frac{a}{2} - \lambda$$

I therefore propose to give tables using the computed values of b, which give somewhat better results than those which depend upon the chart plottings of b, although the difference between the two results shown in the first table computed and that here given for any latitude is only 0°·7 for the 1907 charts, and 1°·2 for the 1700 charts.

For the 1907 charts the mean position of b comes out by the above formula for the northern hemisphere 7°·4 and for the southern 8°·0, and the mean of these 7°·7. Using this value of b the results are as follows:

1907 Charts.

λ	$\frac{a}{2}$	b	*Resulting value of* λ.	*Errors.*
70° N.	75·9	7·7	68°·2	− 1·8
60° N.	67·4	7·7	59°·7	− 0·3
40° N.	49·2	7·7	41°·5	+ 1·5
20° N.	27·0	7·7	19°·3	− 0·7
0° N.	8·5	7·7	0°·8	+ 0·8
20° S.	30·0	7·7	22°·3	+ 2·3
40° S.	48·7	7·7	41°·0	+ 1·0
60° S.	66·3	7·7	58°·6	− 1·4
70° S.	76·3	7·7	68°·6	− 1·4
			Mean error ...	0·0

Dealing now in the same manner with the 1700 charts we find that the mean value of b for the northern hemisphere is 8°·5, and for the southern hemisphere 7°·3, the mean of which is 7°·9. So using this value of b the following results are obtained:

1700 Charts.

λ	$\frac{a}{2}$	b	*Resulting value of* λ.	*Errors.*
70° N.	76·8	7·9	68°·9	− 1°·1
60° N.	68·6	7·9	60°·7	+ 0°·7
40° N.	50·9	7·9	43°·0	+ 3°·0
20° N.	28·5	7·9	20°·6	+ 0°·6
0° N.	7·5	7·9	0°·4	− 0°·4
20° S.	28·4	7·9	20°·5	+ 0°·5
40° S.	49·1	7·9	41°·2	+ 1°·2
60° S.	66·9	7·9	59°·0	− 1°·0
70° S.	74·3	7·9	66°·4	− 3°·6
			Mean error	− 0°·05

The results of these tables are, I venture to think, of some interest. So far as I know they have not been brought out before. If we could assume a sphere so magnetized that for every degree by which the latitude increased there was an increase of one degree in the horizontal dip taken in the true meridian, then it will be clear that while the horizontal dip is changing from 0° at the equator to 90° at the poles, the axial inclinations would increase from 0° to 180°, and since the axial inclination angles, if we disregard declination, are the horizontal dip angles with the

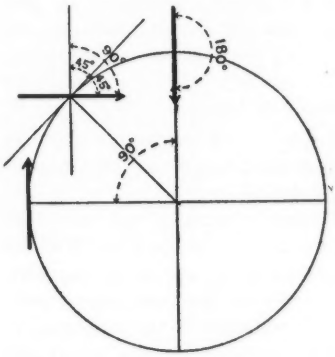
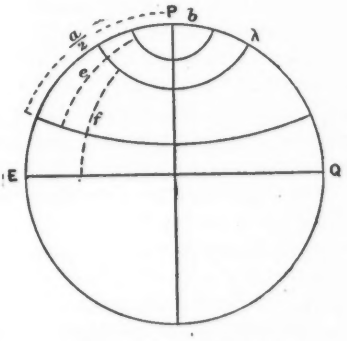


Fig. 6.



$\frac{a}{2} - b = e = f$ *(approx.)*

Fig. 7.

latitude added, in this case half the axial inclination angle would equal the latitude of the place (see Fig. 6). But the earth is clearly not so magnetized, and there are many irregularities in its magnetization; yet from the facts brought out in these charts and tables it appears that the combined result of its magnetization is that the *mean* of half the axial inclination angles taken round any parallel of latitude, minus the distance of the mean centre of all the curves from the geographical poles (shown by a small circle *b* on Fig. 7) is very nearly equal to this latitude

Note written after the Meeting.

I have read Dr. Chapman's notes which follow this paper with considerable interest, and thank him for the trouble he has taken in the matter. Apart from any special consideration his remarks are of importance, as they set forth concisely the application to the subject of the theory that the Earth is uniformly magnetized along a diameter roughly agreeing with that of a line joining the magnetic poles. But there are different opinions amongst authorities as to the normal direction of the Earth's axis of magnetization, and various lines have been suggested by those who are well qualified to deal with the subject, although, perhaps, all have arrived at the conclusion that whatever the primary cause and direction of the magnetizing agency the resulting magnetic axis is inclined at an angle to the geographical axis.

If, in the reduction of my curves, I had selected a line joining the magnetic dip poles, apart from the fact that these are not constant for all times, and so the curves resulting would not be suitable for comparing results of different dates, these poles are not 180° of longitude distant from one another, and consequently the line would not pass through the centre of the Earth; and so I finally came to the conclusion that the only suitable line for the reduction of the curves was that of the geographical axis. Another reason that leads me to conclude that my selection is the most satisfactory one is that the axial inclination curves are, as previously pointed out, perfectly consistent with the distribution of magnetic total intensity, and are deflected just where they might be expected to be, which would not be the case if they had been reduced to an axis joining the magnetic dip poles, or indeed any other axis inclined more than a very few degrees to the geographical axis.

W. Sutherland in 'Terrestrial Magnetism' (vol. 5, p. 73) states that if the Earth carries round an electrostatic field in its rotation (of which there seems good evidence), "then it will have the axis of its magnetic field identical with the axis of rotation, which is the chief approximate fact of the Earth's magnetism. The actual obliquity of the magnetic to the rotational axis is traced to the unsymmetrical magnetic permeability of the Earth." I am inclined to believe that my curves tend to support this theory of the Earth's magnetism.

Taking all things into consideration, I venture to suggest that it is not inconsistent to suppose that the normal direction in which the Earth is magnetized (by east and west electric currents, or some other means) is that of its geographical or rotational axis, although, owing to the unequal magnetic permeability of the material forming its crust the *resulting* magnetic axis, and the lines of force, become oblique and are not in line with the geographical axis.

However, as previously stated, it is not my intention to discuss the theory of Terrestrial Magnetism, and I leave this to others better qualified

to deal with it. All I desire to do is to call attention to the facts brought out by these charts, and I venture to hope that the considerable amount of time and labour I have expended in preparing them may not be altogether in vain.

Before the paper the CHAIRMAN (Dr. H. R. MILL) said: We have met this afternoon to hear a paper on "A Transformation of the Dip Chart" by our friend Mr. Reeves. It is a subject which has been occupying his attention, as I know, for more than a quarter of a century, and on which we used to have many discussions in the old Savile Row days, when we were colleagues in the Society. Every one will hear this paper with the more interest since it has been worked out by the Society's Map Curator in his spare time.

(*Mr. Reeves then read the paper printed above, and a discussion followed.*)

Mr. HINKS: When this paper came into my hands I took an opportunity of referring it to Prof. Schuster, one of the greatest authorities on magnetism in this country, and he kindly sent me the following notes, part of which Mr. Reeves has already quoted to you. Prof. Schuster writes: "The Earth may, roughly speaking, be considered to be a uniformly magnetized sphere, with the axis of rotation inclined to the axis of magnetization. When I first heard from you about Mr. Reeves' result I thought it just possible that it might indicate that the outstanding part (*i.e.* that which cannot be referred to a uniformly magnetized sphere) might be related more nearly to the axis of rotation than to the axis of magnetization. In that case the results of the paper would be of considerable importance; but on looking at the curves I am very doubtful about this point. The dip is rather an awkward element to work with, and it cannot easily be represented in terms of spherical harmonics; but I have assured myself that on the supposition of a uniformly magnetized sphere the lines of equal angle between magnetic force and the direction of the Earth's axis should be closed curves approximating to circles round a point between the magnetic and geographical poles, and one-third of the distance from the geographical pole. This, in fact, is the main feature of Reeves' curves, and the required fraction of distance (1/3) is very nearly satisfied."

Dr. S. Chapman then contributed to the discussion the contribution which is printed as a separate paper, p. 166.

Dr. C. CHREE, F.R.S. (Superintendent, Kew Observatory): I have not had the privilege of seeing the paper, but I may say after hearing it read that I have come to the same conclusion as Prof. Schuster. I am not sure that Dr. Chapman made the position quite clear. The question with regard to the uniform magnetism of the Earth may seem rather an arbitrary assumption. But it is not an assumption; it is a fact. If we take the observational data embodied in charts and treat them mathematically we find that apart from all assumptions the first approximation does give a uniformly magnetized sphere. And we know that the axis about which that uniform magnetic distribution occurs is not the geographical axis, nor the axis approaching most closely to what we know as the magnetic poles, but is inclined 11° or 12° to the geographical axis. So that we know that the first approximation should give us curves centred on an axis, but I should hardly have expected to get actual curves as regular in shape as Mr. Reeves has obtained. I think his doing so is useful, because he has reached his results without any prejudice. I can

also, I hope, appreciate the enormous amount of time he must have given to this laborious work. I was also interested to see that Mr. Reeves referred to some of the late Prof. Fritsche's results. In his lifetime he did a great deal of mathematical work which showed remarkable industry and considerable imagination.

Mr. HINKS: I have been much impressed by the apparent ease with which Dr. Chapman has, in the course of a rather brief week-end, put together a most interesting explanation of the result that Mr. Reeves has put before us. At first sight it is very striking that Mr. Reeves has been able to make those elongated curves of equal dip so very much more circular, and to find that Dr. Chapman is able to give us a simple convincing explanation of that fact is of great interest. As a man very ignorant of magnetism, I should like to ask if, when Dr. Chree says that the Earth to a very close degree of approximation is uniformly magnetized about a certain axis, his axis is a diameter of the spheroid?

Dr. CHREE: Yes.

Mr. HINKS: In spite of the fact that the line joining the magnetic poles is so far from being a diameter that it passes something like 1000 miles from the centre of the Earth?

Dr. CHREE: Something like that. The position of the south pole is not very accurately known, as a matter of fact.

Mr. HINKS: I think Prof. David fixed it within a few miles.

Dr. CHREE: And other people have found it otherwise.

Mr. HINKS: Yes, but I think Prof. David has some claim to be considered as the authority. He is the only man who has made observations near it.

Dr. CHAPMAN: There does not seem much difficulty in defining the position of the magnetic poles. I think that the distance in question is 700 miles.

Mr. HINKS: In any case the line joining the magnetic poles runs at least 700 miles from the Earth's centre, so that it seems we are in the presence of another extraordinary fact: that although the magnetic poles are so unsymmetrical upon the Earth, you can by assuming uniform magnetism about a line which does not pass very nearly through either of them, arrive at results which are to a considerable degree of approximation the results observed.

Dr. CHAPMAN: Your mathematical representation requires the magnetic axis to pass through the centre of the Earth, and by that means you can get an approximation to the observed fact.

Mr. HINKS: When you call it a first approximation, how satisfactory an approximation is it? For instance, within what percentage does it give the intensity?

Dr. CHREE: I think somewhere about 85 per cent. The data on which the mathematical solution is based are really from latitudes between 60° N. and 60° S., though the mathematical conclusions are not restricted to that area. You simply assume that there is a distribution possible in spherical harmonics, and then you determine the constants of that distribution from the data of your charts; and what you find is that the coefficients of the first-order terms are very much the biggest. But different people dealing with data from different sources differ considerably as to the results for the higher-order terms.

Dr. J. W. EVANS: I should like to ask Dr. Chapman and Dr. Chree how far this axis, which is the basis of the first approximation to the uniformly magnetized Earth, how far that agrees with the Earth's poles? Is that also approximately one-third the distance from the pole of rotation?

Dr. CHREE: It is about 12° away from the axis of rotation, and in much the same azimuth.

Dr. EVANS: I was very interested in Mr. Reeves' work, which is a great advance, at any rate, on the popular understanding and appreciation of the distribution and direction of the dip over the whole Earth. It seems to me an extraordinary fact, and quite contrary to what one would expect, that the maximum magnetization should be in the direction of the great continental masses; for if there is one thing we thought we were assured of, it was that the great continental masses represent the regions where there is the greatest thickness of non-ferruginous material, where the earth is mainly composed of sedimentary and of granite rocks, in which there is the least material to affect magnetism. There is evidently a fallacy somewhere.

Dr. CHAPMAN: I was looking up two papers in the French Academy. Mr. Wilde has found that the distribution of magnetism over the Earth's surface can be represented if you have a uniformly magnetized sphere and over it lay slips of sheet-iron covering the ocean. He finds that that reproduces the positions of the two magnetic with reference to the geographical poles, and that was confirmed by Mons. Idrac about four years ago. And M. Recluse last year tried to explain that by showing that beneath the oceans there is a layer of iron cooler than that under the land; that is to say, that this layer of iron is below the temperature at which magnetization became impossible, so that there may be a layer of iron under the ocean which is sufficiently cool at a depth where the iron layer is in order to magnetize and correspond with these strips of sheet-iron which they used.

The CHAIRMAN: I should like to thank Mr. Reeves for bringing this matter before us, and also Dr. Chapman and Dr. Chree for the lucidity with which they have brought the light of theory to bear upon the results of observation. It is gratifying to find that the result of a piece of patient investigation of actual facts, without the guidance of any theory whatsoever, should produce such a charmingly symmetrical result; and that this symmetrical result should be so perfectly explained by a theory that does not require to be strained in order to fit it. It makes one wonder why these lines have not been suggested by theory before Mr. Reeves had with pain and labour dug them out and displayed them on a globe in this manner.

Mr. REEVES: I am very much obliged to Dr. Chapman, Dr. Chree, and Dr. Mill for their remarks. There is no theory about what I have done; it is simply practical application of observations, plotted in a new way. When you do that you get much more regular and, to my mind, more reasonable curves than if you take the ordinary dip measured from the horizon. The work I have been doing is more or less connected with some experimental work of my own which is interesting me considerably, and perhaps some day I may have the honour of showing it here.